

I claim:

1. A positioning system operative on a base structure comprising, in combination,

- a. a reaction frame assembly including a reaction frame mounted on the base structure,
- b. an object stage for movement relative to an object stage base,
- c. means for supporting said object stage in space from said object stage base and independent of said reaction frame,
- d. cooperating force type linear actuator means mounted on said object stage and said reaction frame assembly for positioning of said object stage

whereby said object stage base and said object stage are isolated from reaction forces from said force actuator means and whereby coupling of vibrations to said object stage base and said object stage are minimized.

2. The positioning system of claim 1 wherein said reaction frame assembly includes an independently movable follower for following said object stage .

3. The positioning system of claim 1 wherein said actuator means includes at least one linear motor operating between said object stage and said reaction frame assembly.

4. The positioning system of claim 1 including at least a pair of actuator means for positioning said object stage, each of said actuator means having a drive member mounted on said object stage.

5. The positioning system of claim 4 wherein the vector sum of the moments of force at the center of gravity of the object stage due to the positioning forces of the drive members is substantially equal to zero.

5 6. The positioning system of claim 2 including at least one drive member mounted on said object stage.

7. The positioning system of claim 2 wherein said follower includes a pair of arms which are respectively movable in a pair of parallel planes with the center of gravity of the object stage therebetween.

8. The positioning system of claim 1 wherein said object stage is moveable in at least a first direction and a second direction at an angle to the first direction, a first follower for moving and following said object stage only in said first direction and a second follower for moving and following said object stage only in said second direction and said cooperating actuator means mounted on said object stage and said first and second followers for positioning of said object stage in said first and second directions.

9. The positioning system of claim 8 wherein said actuator means includes at least three force type linear actuators operating between said object stage and said reaction frame assembly.

10. The positioning system of claim 9 wherein a pair of said at least three linear actuators is mounted for driving said object stage in said first direction wherein the vector sum of the moments of force at the center of gravity of the object stage due to the positioning forces of cooperating actuator means is substantially equal to zero.

11. The positioning system of claim 10 wherein one of said linear actuators other than said pair of linear actuators is mounted on said object stage for driving said object stage in said second direction wherein the vector sum of the moments of force at the center of gravity of the object stage due to the positioning forces of cooperating actuator means is substantially equal to zero.

12. The positioning system of claim 8 including at least two pair of linear actuators for positioning said object stage, one of said pairs of linear actuators for positioning said object stage in said first direction and the other of said pairs of linear actuators for positioning said object stage in said second direction, the vector sum of the moments of force at the center of gravity of the XY stage due to the positioning forces of cooperating actuator means being substantially equal to zero.

13. The positioning system of claim 8 wherein each of said first and second followers includes a pair of spaced apart arms, the arms of one of said followers positioned and movable in a single plane and the arms of the other of said followers positioned and movable in a pair of parallel planes with said single plane positioned therebetween.

14. The positioning system of claim 13 wherein the center of gravity of said object stage is in or immediately adjacent to said single plane.

15. Positioning apparatus comprising, in combination,
- a. an object stage for movement in at least a first direction and a second direction at an angle to the first direction,
  - b. a first follower for moving and following said object stage only in said first direction and
  - c. a second follower for moving and following said object stage only in said second direction and
  - d. cooperating linear force actuator means mounted on said object stage and said first and second followers for positioning of said object stage in said first and second directions.

16. The positioning apparatus of claim 15 wherein said actuator means includes at least three force type linear actuators operating between said object stage and said followers.

17. The positioning apparatus of claim 16 wherein a pair of said at least three linear actuators is mounted for driving said object stage in said first direction and wherein the vector sum of the moments of force at the center of gravity of the object stage due to the positioning forces of cooperating actuator means is substantially equal to zero.

18. The positioning apparatus of claim 17 wherein one of said linear actuators other than said pair of linear actuators is mounted on said object stage for driving said object stage in said second direction and wherein the vector sum of the moments of force at the center of gravity of the object stage due to the positioning forces of cooperating actuator means is substantially equal to zero.

19. The positioning apparatus of claim 15 including at least two pair of linear actuators for positioning said object stage, one of said pairs of linear actuators for positioning said object stage in said first direction and the other of said pairs of linear actuators for positioning said object stage in said second direction, wherein the vector sum of the moments of force at the center of gravity of the object stage due to the positioning forces of cooperating actuator means is substantially equal to zero.

20. The positioning apparatus of claim 15 wherein each of said first and second followers includes a pair of spaced apart arms, the arms of one of said followers positioned and movable in a single plane and the arms of the other of said followers positioned and movable in a pair of parallel planes with said single plane positioned therebetween.

21. The positioning apparatus of claim 20 wherein each of said followers includes at least one drive member wherein the vector sum of the moments of force at the center of gravity of the object stage due to the positioning forces of cooperating drive members is substantially equal to zero.

22. The positioning apparatus of claim 20 wherein the center of gravity of said object stage is in or immediately adjacent to said single plane.

23. The positioning apparatus of claim 15 including an object stage base, a reaction frame assembly having a reaction frame mounted on a base structure, means for supporting said followers from said reaction frame assembly, means for supporting said object stage in space from said object stage base and independent of said reaction frame whereby said object stage base and said object stage are isolated from vibrations caused by

their reaction forces whereby vibrations of said object stage base and said object stage are minimized.

24. An alignment apparatus comprising, in combination,

- a. a XY stage having a center of gravity,
- b. means for supporting said XY stage in space from an XY stage base,
- c. a reaction frame assembly including a reaction frame supported on a reaction frame base independent from said XY stage base,
- d. said reaction frame assembly including an independently movable X follower and an independently movable Y follower, said X follower movably mounted on said reaction frame and movable in a X direction and said Y follower movably mounted on said reaction frame and movable in a Y direction,
- e. one of said X and Y followers having at least a pair of spaced apart arms and the other of said X and Y followers having at least one arm, and
- f. cooperating force type linear actuator means mounted between said XY stage and said followers for horizontally positioning said XY stage in space,
- g. said actuator means including a drive element means on each of said follower arms and

corresponding drive member means on said XY  
stage cooperating with said drive element  
means for positioning said XY stage  
whereby said XY stage base and said XY stage are isolated from  
5 vibrations caused by reaction forces whereby vibrations of said  
XY stage base and said XY stage are minimized.

25. The alignment apparatus of claim 24 wherein said  
arm on said other of said X and Y followers is movable in a  
single plane and said arms of said pair of arms on said one of  
10 said X and Y followers are positioned and movable in a pair of  
separate planes with said single plane therebetween.

26. The alignment apparatus of claim 25 including  
means for mounting and controlling said drive element means on  
said pair of arms of said one follower wherein the vector sum of  
15 the moments of force at the center of gravity of the XY stage due  
to the positioning forces of cooperating drive member means is  
substantially equal to zero.

27. The method of positioning an object comprising the steps of:

- a. positioning a reaction frame on a base,
- b. supporting the object on an object stage,
- c. supporting said object stage at a position in space and from an object stage base independent of said reaction frame, and
- d. applying forces between said object stage and said reaction frame to drive said object stage in at least one direction to a new position in space while isolating said object stage base from reaction forces due to said applied .

28. The method of positioning an object stage in space by movement in a first direction and in a second direction with at least a first follower and a second follower comprising the steps of:

- a. supporting said object stage in space,
- b. applying forces between said object stage and said first follower to drive said object stage only in said first direction,
- c. applying forces between said object stage and said second follower to drive said object stage only in said second direction,



- d. driving said first follower to follow said object stage only in said second direction and independent of said second follower and
- e. driving said second follower to follow said object stage only in said first direction and independent of said first follower.

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29. The positioning system of claim 1 including means for coupling said actuator means between said object stage and said reaction frame wherein the coupling is rigid in at least the drive force direction.

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30. The positioning apparatus of claim 15 including means for coupling said actuator means between said object stage and said followers wherein the coupling is rigid in at least the drive force direction.

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31. The positioning system of claim 24 including means for coupling said actuator means between said XY stage and said followers wherein the coupling is rigid in at least the drive force direction.

32. A precise positioning apparatus provided for cooperation with a base plate having a flat surface and a movable stage for moving along a predetermined direction on the flat surface of said base plate, comprising:

- a. a first supporting assembly for supporting said base plate on a foundation;
- b. an actuator assembly for supplying electro-magnetic force to said movable stage along said predetermined direction, said actuator assembly including:
  - i) a movable driven portion connected with said movable stage to be movable in said predetermined direction; and
  - ii) a drive portion located around said movable stage; and
  - iii) one of said driven and said drive portions having a coil unit and the other having a magnetic unit; and
- c. A second supporting assembly for supporting said drive portion on said foundation independently from said first supporting assembly so as to make a predetermined gap between said coil unit and said magnetic unit.

33. The positioning apparatus of claim 32 wherein said drive portion of said actuator assembly is held in a static position with respect to said predetermined direction.

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